High Energy Large Area Surveys: from BeppoSAX to Chandra and XMM

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Abstract. Optical identification of hard X-ray selected BeppoSAX and Chandra sources indicates that a large fraction of the sources are "intermediate" AGN, i.e. type 1.8-1.9 AGN, broad-line quasars and even X-ray loud but optically dull (apparently normal) galaxies, all obscured in X-rays by columns of the order of $10^{22-23.5}$ cm^{-2}. Because of this obscuring matter, these sources are more difficult to detect or select at other wavelengths, implying that a fraction of the accretion power in the Universe may have been missed so far.

1 Introduction

The characteristic shape of the X-ray Cosmic background (XRB) strongly suggests that most (80-90 %) of the accretion luminosity in the Universe is obscured (e.g. Hasinger et al. 1999, Fabian & Iwasawa 1999, Hasinger et al. 2000). Hard X-ray surveys are therefore the most efficient way to trace accretion, since obscured, accreting sources are more difficult to detect or select at other wavelengths. Furthermore, the source classification based on optical-UV lines is based on "secondary" properties (e.g. emission lines from ionized plasma) and so may be inaccurate and/or incomplete (see for example the cases of NGC6240, Vignati et al. 1999 and NGC4945, Guainazzi et al. 2000). Conversely, hard X-ray selection and classification are based on "primary" properties: the emission from a region close (10-100 gravitational radii) to the central supermassive black hole. Hard X-ray surveys can then be used to record the "accretion history" of the Universe, i.e. the history of the light ultimately produced by gravity. This can be compared with the history of the formation of structures in the Universe, from proto-galaxies, to galaxies, to groups and clusters, which again is driven by gravity, and to the history of the star-formation, i.e. the history of the light produced by nuclear reactions in stars. These comparisons can give us a clue on the correlations between the formation and light-up of supermassive black holes in galactic nuclei and galaxy formation and evolution. For example, Fabian (1999) has proposed a scenario in which powerful radiation driven winds emerge from newly born quasars, possibly affecting the star-formation processes in the nearby gas clouds and the mixing of the ISM in the host galaxy. In this scenario the powerful high redshift, newly born quasars are expected to be highly obscured (actually the majority of them would be Compton-thick), and therefore nearly invisible at optical-UV and soft X-ray energies. Alternatively, the bulk of the hard XRB may be due to a large population of relatively low luminosity (Seyfert-like) AGN at moderate redshift (z$<$ 1). If this is the case a large fraction of the galaxies at these redshifts should host an active nucleus. Hard X-ray surveys can help in disentangling between these competing scenarios. We present here a work-in-progress on our High Energy Large Area Survey which makes use at the moment of BeppoSAX and Chandra data. XMM data will be included as soon as the first fields will become public. Our approach is complementary to deep pencil beam surveys (e.g. Giacconi et al. 2000, Hasinger et al. 2000) in that we cover different portions of the redshift–luminosity plane. Our purpose is to study cosmic source populations at fluxes where a large fraction of the hard XRB is resolved ($\approx 50\%$), but where a) the X-ray flux is high enough to provide at least rough X-ray spectral information; b) the area covered is as large as possible, to be able to find sizeable samples of "rare" objects; and c) the magnitude of the optical counterparts is bright enough to allow relatively high quality optical spectroscopy, useful to investigate the physics of the sources.

2 X-ray data and optical identifications

The BeppoSAX HELLAS survey covers ~ 55 deg^2 of the sky with $\delta < +79$, $20 < \alpha < 5$ and $6.5 < \alpha < 17$ at 5-10 keV fluxes in the range $5\times10^{-14}-10^{-12}$ erg cm^{-2} s^{-1} (Fiore et al. 2000a). The Chandra survey covers about half deg^2 at a 2-10 keV flux limit of 10^{-14} erg cm^{-2} s^{-1} (Fiore et al. 2000b, Cappi et al. 2000). About half of the BeppoSAX (62) and Chandra (17) sources have been optically identified. Because of the quite large MECS error box ($\sim 1'$ radius, Fiore et al. 2000a), we limit the optical identification process of BeppoSAX sources to objects with surface density $\lesssim 40$ deg^{-2}, to keep the number of spurious identifications in the whole sample smaller than a few percent. This translate in the following limits on the magnitude of the possible optical counterparts: R$<$ 20.5 for broad-line AGN; R$<$ 19 for narrow-line AGN; R$<$ 17.5 for emission line galaxies (LINERs and starburst galaxies). According to these limits about one third of the BeppoSAX error boxes studied in detail remain "unidentified". Results on the optical identification of BeppoSAX and Chandra hard X-ray sources have been presented by Fiore et. al. (1999), Fiore et al. (2000b), Cappi et al. (2000), La Franca et al. (2001), in preparation. Here we limit the discussion to the following three main topics.

2.1 The fraction of obscured to unobscured AGN

To study the spectral variety of the HELLAS sources we have calculated for each source the softness ratio (S-H)/(S+H) (S=1.3-4.5 keV, H=4.5-10 keV count rates for the BeppoSAX sources and S=0.5-2 keV, H=2-10 keV fluxes for the Chandra sources). (S-H)/(S+H) is plotted as a function of the redshift in figures 1a (BeppoSAX) and 1b (Chandra). While broad line AGN are identified up to z=2.76, all narrow line AGN in figure 1a have z<0.4. This is due very likely to the conservative threshold adopted for the optical magnitude of narrow emission line AGN and galaxies (which do not show a bright optical nucleus, because of the strong extiction). Because of its relatively large error-boxes BeppoSAX cannot be used to unambiguously identify high redshift, narrow line AGN and galaxies. The dotted lines in figures 1a,b represent the expectation of unabsorbed power laws with $\alpha_E = 0.4$ and 0.8. The dashed lines represent the expectations of a power law model absorbed by columns of increasing densities (in the source frame). Many BeppoSAX and Chandra HELLAS sources have (S-H)/(S+H) inconsistent with that expected from unabsorbed power law models with $\alpha \sim 0.8$. Absorbing columns of the order of $10^{22.5-23.5}$ cm^{-2} are most likely implied. The fraction of highly obscured sources ($N_H \gtrsim 10^{23}$) in figure 1a at z< 0.3 (where our survey should be representative of the actual source population) is ~ 0.42. This is consistent with the expectations of AGN synthesis models (Comastri et al. 2000 in preparation). In this redshift range all highly obscured objects are narrow line AGN and galaxies, while all broad line AGN have $N_H < 10^{23}$ cm^{-2}, consistent with popular AGN unification schemes.

2.2 Absorption versus extintion in high redshift AGN

The situation is different at high redshift. Several broad line AGN at z> 0.5 have (S-H)/(S+H) inconsistent with that expected for a $\alpha_E \sim 0.8$ power law. The (S-H)/(S+H) of broad line AGNs in figure 1a (24) and 2b (18) are marginally anticorrelated with z (Spearman rank correlation coefficent of -0.364 for 22 dof, and -0.52 for 16 dof, corresponding to probabilities of 92% and 97.3 % respectively). The number of sources is not large enough to reach a definite conclusion, but it is interesting to note that this correlation goes in the opposite direction than expected. In fact, the ratio of the optical depth in the optical band, due to dust extinction, to that in the X-ray band, due to photoelectric absorption, should scale as $(1 + z)^4$. Highly X-ray obscured broad line blue continuum quasar can exist only if their dust to gas ratio or their dust composition strongly differs from the Galactic one (see e.g. Maiolino et al, 2000), or if the X-ray absorber is within the Broad Line Region. Similar results have been recently found in ASCA samples by Akiyama et al. (2000) and Della Ceca et al. (1999). A low dust-to-gas ratio may be obtained if most of the X-ray absorbing gas is within the sublimation radius of the dust, i.e. close to the central X-ray source. The sublimation radius depends

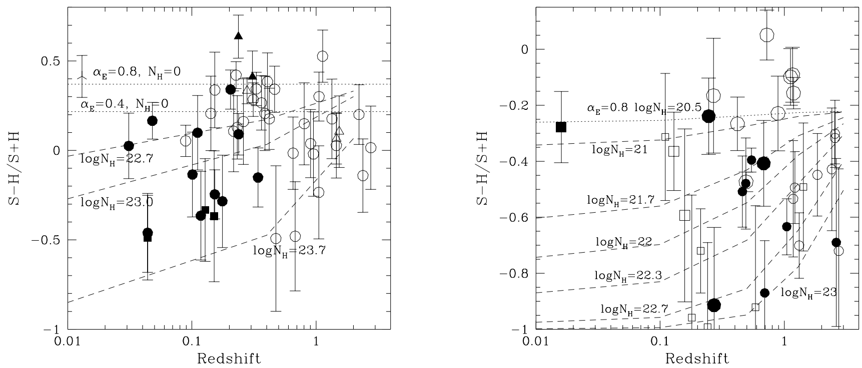

Fig. 1. a) BeppoSAX MECS (S-H)/(S+H) (S=1.3-4.5keV, H=4.5-1 keV count rates) versus the redshift for the identified sources. Open circles = broad line, quasars and Sy1; filled circles = type 1.8-1.9-2.0 AGN; filled squares = starburst galaxies and LINERS; open triangles = radio-loud AGN; open squares = optically 'normal' galaxies. Dotted lines show the expected softness ratio for a power law model with α_E=0.4 (lower line) and $\alpha_E = 0.8$ (upper line). Dashed lines show the expectations of absorbed power law models (with $\alpha_E = 0.8$ and logN_H=23.7, 23.0, 22.7, from bottom to top) with the absorber at the source redshift. b) Chandra ACIS (S-H)/(S+H) (S=0.5-2keV, H=2-10keV fluxes) versus the redshift for the Chandra HELLAS sources (big symbols) and the Barger et al. (2000) and Giacconi et al. (2000) identified sources (small symbols). Dashed lines show the expectations of absorbed power law models (with $\alpha_E = 0.8$ and logN_H=23, 22.7, 22.3, 22, 21.7, 21 and 20.5 (from bottom to top) with the absorber at the source redshift.

on the luminosity of the X-ray source, and so sources with gas at similar distances from the X-ray source will show low/high extinction depending on the high/low luminosity of the central source. Large dust masses illuminated and heated-up by the strong AGN UV-to-X-ray continuum would re-emit in the infrared. Based on the average AGN spectral energy distribution, on the XRB intensity and on the assumption that most of it is due to obscured active nuclei Fabian & Iwasawa (1999) estimated that between 10% and 50% of the 100 micron background could be due to reprocessing of accretion radiation, compared to dust reprocessed starlight radiation. If however a significant fraction of the XRB is actually due to broad-line, dust-free, X-ray obscured quasars, then the contribution to the IR background of the sources making the hard XRB would be smaller than the above values.

2.3 X-ray loud optically dull galaxies

The unprecendented Chandra arcsec position determination allows for the first time to unambiguously identify X-ray emitting, optically faint galaxies

(Barger et al. 2000, Hornschemeier et al. 2000, Fiore et al. 2000b, Giacconi this meeting). In several cases their X-ray to optical ratio is 10-100 times that of nearby galaxies. Intriguingly, the X-ray spectrum of these galaxies is often hard: the softness ratio in figure 1b implies in several cases substantial column densities, for a typical AGN X–ray continuum (see figure 1b, open squares). The relatively high X-ray luminosity, compared to the optical one, suggests an X-ray active nucleus in these objects, in which either continuum beaming dominates (as in BL Lacertae objects), or emission lines are obscured or not efficiently produced, although more exotic possibilities (like Advection Dominated Accretion Flow) cannot be excluded at this point. AGN optical emission lines could be hidden by the X-ray absorbing gas. There are several cases in which X-ray AGN do not show up in the optical band, see e.g. the highly obscured AGN NGC4945 (Marconi et al. 2000, Guainazzi et al. 2000) and NGC6240 (Vignati et al. 1999 and references therein). In these cases strong emission lines are present in the optical spectra, but they are due to starburst regions, as indicated by their intensity ratios. Conversely, the X-ray loud optically dull galaxies have very red optical spectra implying an old stellar population and little star-formation.

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